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Date	June 15, 2007	Reg. No. 42,845

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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of:	)	Group Art Unit:	2618
	)		
John Santhoff et al.	)	Examiner:	Nguyen Thanh Vo
	)		
Serial No.: 10/719,903	)	Confirmation No.:	4045
	)		
Filed: November 21, 2003	)		
	)		
For: BRIDGED ULTRA – WIDEBAND COMMUNICATION METHOD AND APPARATUS	)))))		
	)		

Carlsbad, California
June 14, 2007

MAIL STOP APPEAL BRIEF - PATENTS
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

REPLY BRIEF

Dear Sir/Madam:

This reply brief is submitted under 35 U.S.C. §134 and is in accordance with 37 C.F.R. Parts 1, 5, 10, 11, and 41. This reply brief is in response to the Examiner's Answer, mailed April 17, 2007, and is mailed within two months of that date.

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Table of Contents

(1)   Real Party in Interest

The real party in interest is Pulse-Link, Inc.

(2)   Related Appeals/Interferences

No other appeals or interferences exist which relate to the present application or appeal.

(3)   Status of Claims

Claims 1-25 are pending and rejected.

(4)   Status of Amendments

No amendments are outstanding.

(5)   Summary of Claimed Subject Matter

As an initial matter, it is noted that according to the Patent Office, the concise explanations under this section are for Board convenience, and do not supersede what the claims actually state, 69 Fed. Reg. 155 (August 2004), see page 49976. Accordingly, nothing in this Section should be to change (e.g., broaden, narrow) the scope of the claims by the process of claim interpretation, prosecution history estoppel or in any other manner, for purposes of this appeal and/or subsequently to this appeal.

As set forth in independent claim 1, the invention provides a system for communication between different communications technologies. For example, in one embodiment of the present invention, a conventional narrowband receiver receives data. The data is then demodulated by a demodulator. A transmitter that is structured to transmit a plurality of electromagnetic pulses receives the data from the demodulator, and transmits the data, using the electromagnetic pulses.

The communication system of the present invention enables communication between two specific, yet very different, communication technologies. One is conventional narrowband technology that employs a substantially continuous sine wave carrier signal, and the other is ultra-wideband technology that employs a plurality of electromagnetic pulses.

As discussed in Applicant's specification (pages 6-8) and in the Scientific American and Microwave Journal articles attached in **Appendix B**, ultra-wideband (UWB) communication technology is "vastly different" from conventional technology that employs substantially continuous carrier waves. However, once UWB is deployed, it will operate

alongside conventional communication technologies. The present invention provides a system that enables communication between the two very different technologies.

(6)   Grounds of Rejection to be Reviewed on Appeal

Whether claims 1-25 are unpatentable under U.S.C. § 103(a) as being obvious in light of U.S. Patent 6,360,075 ("Fischer") in view of U.S. Patent 6,515,622 ("Izadpanah"").

(7)   Argument

Below, Appellant responds to the comments presented in the Response to Argument section of the Examiner's Answer.

(7A)   Claim Differentiation Requires Independent claim 1 to Have a Different Meaning and Scope than Dependent claims 2 and 17

The Examiners reading of a modulation limitation into claim 1 is incorrect as the Examiner is reading limitations into the claim. "Modulation" or a specific modulation method are not recited in Appellant's claim 1, and the doctrine of claim differentiation prevents reading this limitation into the claim.

Specifically, the Examiner responds to Appellants' position that claim 1 does not recite modulation techniques and therefore any discussion of modulation is irrelevant. The Examiner states:

> "Claim 1 recites "the transmitter structured to transmit a plurality of electromagnetic pulses, with the pulses configured to include the communication data" (emphasis added by examiner). Since the communication data are included in the transmitted pulses as recited in the claim, it is a pulse modulation. In order to support the examiner's position, the

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examiner would like to direct appellant's attention to claim 17 which depends from claim 1. Claim 17 clearly recites "an ultra-wide **pulse modulation"** (emphasis added by examiner). Different modulation techniques are also recited in dependent claim 2. <u>Therefore, claim 1 does recite a specific modulation technique.</u> Accordingly, the examiner's discussion of different modulation techniques is not irrelevant as alleged by appellant." (bold in original, underline added)

However, the doctrine of claim differentiation requires that the claims have different meanings and scope, and that limitations stated in dependent claims are not to be read into the independent claim from which they depend. *Karlin Tech. Inc. v. Surgical Dynamics Inc.,* 177 F.3d 968, 50 USPQ2d 1465 (Fed. Cir. 1999). Put differently, an independent claim should not be construed as requiring a limitation added by a dependent claim. Appellants' independent claim 1 and dependent claims 2 and 17 are a perfect illustration of this doctrine. Claim 1 recites :

> A communication system comprising:
> <u>a receiver structured to receive a substantially continuous sine wave carrier signal,</u> the signal modulated to contain communication data;
> a demodulator communicating with the receiver, the demodulator structured to demodulate the communication data from the substantially continuous sine wave carrier signal; and
> <u>a transmitter coupled to the demodulator, the transmitter structured to transmit a plurality of electromagnetic pulses,</u> with the pulses configured to include the communication data. (underline added)

Claim 2 recites:

> The communication system of claim 1, <u>wherein the substantially continuous sine wave carrier signal</u> is selected from a group consisting of: an amplitude modulated signal, a phase angle modulated signal, a frequency angle modulated signal, an orthogonal frequency division multiplexing modulated signal, a quadrature amplitude modulation signal, a dual sideband modulated signal, a single sideband modulated signal, and a vestigial sideband modulated signal. (underline added)

And claim 17 recites:

> The communication system of claim 1, <u>wherein the transmitter comprises an ultra-wideband pulse modulator</u> that is structured to transmit a multiplicity of ultra-wideband pulses. (underline added)

Thus, claim 2 recites different types of **signal modulations** that may be received by the **receiver** recited in claim 1. Claim 17 recites that the transmitter is an ultra-wideband pulse **modulator**, in contrast to the "ultra-wide **pulse modulation"** asserted by the Examiner. A "modulator" is **NOT** a type of "modulation", which is discussed in detail starting on page 15, line 9 of Appellants' specification.

In summary, in view of the doctrine of claim differentiation, claim 1 recites a communication system, claim 2 recites different signal modulations that may be received by the communication system, and claim 17 recites a component of a transmitter. Any attempt to read the limitations of claim 2 into claim 1 would make claim 2 superfluous. And claim 17 recites a "modulator" not a "modulation." Therefore, the Examiner's statement that "claim 1 does recite a specific modulation technique" is completely incorrect, and is an improper attempt to read limitations into claim 1.

<u>(7B)   Claim 1 recites two different types of communication technologies: 1) a receiver that receives continuous sine wave carrier signals; and 2) a transmitter that transmits a plurality of electromagnetic pulses.</u>

The Examiner states:
> "In response to appellant's argument that the references fail to show certain features of appellant's invention, it is noted that the features upon which appellant relies (i.e., two different **communication technologies**) are <u>not</u> recited in the rejected claim(s). Although the claims are interpreted in light of the specification, limitations from the specification are not read into the claims. See *In re Van Geuns,* 988 F.2d 1181, 26 USPQ2d 1057 (Fed. Cir. 1993). The claims do not recite what is called "communication technique". For

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this reason, appellant's discussion of communication techniques is irrelevant. In addition, the claimed invention of claims 1-25 reads on a system that can employ two different modulation techniques, wherein the first modulation technique is explicitly defined in claim 2, and the second modulation technique is explicitly defined in claim 17. As clearly stated in the rejection to claims 1-25 above, the combination of Fischer and Azadpanah does disclose a system that employs two modulation techniques (see Fischer, figure 2 which shows two modulation techniques such as QPSK modulation and QAM64 modulation. See also column 5 lines 10-53)." (bold in original, underline added).

As discussed above, claim 17 does not recite a **modulation**, but instead recites a **modulator**. As discussed at length in Appellant's specification, starting on page 15, line 9, modulation is the process of modifying a signal to represent information to be transmitted. This process is performed by a modulator, as recited in claim 17 ("an ultra-wideband pulse modulator"). But claim 17 does NOT recite a specific modulation method.

To be clear, claim 1 recites, in part, "a receiver structured to receive a substantially continuous sine wave carrier signal," and "a transmitter coupled to the demodulator, the transmitter structured to transmit a plurality of electromagnetic pulses."

A substantially continuous sine wave carrier signal is not a plurality of electromagnetic pulses, and a plurality of electromagnetic pulses are not a substantially continuous sine wave carrier signal. That is, claim 1 claims a first type of communication technology in the form of a receiver that receives a continuous sine wave carrier signal, and a second type of communication technology in the form of a transmitter that transmits a plurality of electromagnetic pulses.

These two types of different communication technologies are discussed in detail starting on page 6, line 13, with reference to FIGS. 1 and 2, of Appellants' specification. In addition, attached in **Appendix B** (also submitted in Appellant's Appeal Brief) are Scientific

American and Microwave Journal articles, that describe the two communication technologies as "vastly different."

So, in fact, two different types of communication technology are recited in claim 1.

Appellant does agree with the Examiner when he states that "the claimed invention of claims 1-25 reads on a system that can employ two different modulation techniques." In fact, claim 1 reads on many more than two types of modulation techniques. However, as discussed above, modulation techniques are not being claimed by Appellant in claim 1, and therefore, the Examiner's line of reasoning is completely irrelevant. **The Examiner cannot read limitations into claim 1 that are either: 1) not found in the claim; or 2) are found in the dependent claims.**

(7C)   There is No Motivation to Combine the References for the Following Reasons:

1)   The prior art does not suggest the desirability of the claimed invention; and

2)   The proposed modification changes the principal of operation of the primary reference.

The Examiner supports his modification of Fischer with Izadpanah as follows:

> First, in response to appellant's argument that Fischer and Izadpanah are not combinable because Fischer and Izadpanah use two different communication technologies, the test for obviousness is not whether the features of a secondary reference may be bodily incorporated into the structure of the primary reference; nor is it that the claimed invention must be expressly suggested in any one or all of the references. Rather, the test is what the combined teachings of the references would have suggested to those of ordinary skill in the art. See *In re Keller,* 642 F.2d 413, 208 USPQ871 (CCPA1981).
>
> Second, in response to appellant's argument that there is no suggestion to combine the references, the examiner recognizes that obviousness can only be established by combining or modifying the teachings of the prior art to produce the claimed invention where there is some teaching, suggestion, or

motivation to do so found either in the references themselves or in the knowledge generally available to one of ordinary skill in the art. See *In re Fine,* 837 F.2d 1071, 5 USPQ2d 1596 (Fed. Cir. 1988) and *In re Jones,* 958 F.2d 347, 21 USPQ2d 1941 (Fed. Cir. 1992). <u>In this case, the motivation to combine references is found in the references themselves (namely, the ultra wideband pulse system has advantages such as lowered probability of intercept of transmission, reduced multipath fading and radio frequency interference problems, as suggested by Izadpanah at column 1 lines 11-18</u>). (underline added)

1)   The Prior Art Does Not Suggest the Desirability of the Claimed Invention.

Appellant agrees with the Examiner that "the test is what the combined teachings of the references would have suggested to those of ordinary skill in the art." However, in the absence of an express teaching or suggestion to combine references, as in this case, the "test for an implicit showing is what the combined teachings, knowledge of one ordinary skill in the art, and the nature of the problem to be solved as a whole would have suggested to those of ordinary skill in the art." M.P.E.P. Section 2143.01(I), *In re Kotzab,* 217 F.3rd 1365, 1370, 55 USPQ2d 1313, 1317 (Fed. Cir. 2000).

1a)   The Nature of the Problem to be Solved and the Combined Teachings of the Prior Art

The primary reference, Fischer, addresses the problem of providing data-intensive services in limited frequency spectrum (col. 2, lines 6-9). In the Background of the Invention section, Fischer discusses consumers' insatiable appetite for information and entertainment, and several different "pipelines" used to deliver that information to consumers. Internet via telephone lines, computer modems, wireless TV broadcasts, cable TV using coax cable and wireless cable using microwave signals. Fischer solves the

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problem by providing a way to increase the date rate transmitted through analog multichannel multipoint distribution systems (MMDS), multipoint distribution systems (MDS) and instructional television fixed services (ITFS) (col. 3, lines 53-58). These are "standard 6 MHz video channels as used in conventional analog video transmission" (col. 3, line 61-63).

The secondary reference, Izadpanah, is concerned with a completely different problem, specifically, "ultra-wideband phased array antennas for radio frequency and optical beam forming" (col. 1, lines 6-8). Izadpanah teaches "a method and apparatus for forming ultra wideband phased array antenna beams with no beam squint" (col. 2, lines 25-28).

So Fischer is interested in finding a way to increase data rates in a conventional TV system, and Izadpanah wants to build a phased array antenna for ultra-wideband communications.

Fischer does not recognize a need for a transmitter that transmits a plurality of electromagnetic pulses, as taught in Izadpanah, and Izadpanah does note recognize a need for a receiver that receives continuous sine wave carrier signals, as taught in Fischer.

Fischer does not teach or suggest using ultra-wideband technology in his listing of "pipelines" or anywhere else in his specification.

Izadpanah fails to teach or suggest anything related to conventional TV communication technology. Moreover, Izadpanah is also completely silent as to any data rates.

As neither reference addresses the same problem, and neither recognizes the need for a communication system that can employ two different communication technologies, there is no motivation to combine the references.

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Finally, the motivation provided by the Examiner, that "the ultra wideband pulse system has advantages such as lowered probability of intercept of transmission, reduced multipath fading and radio frequency interference problems" is nonsensical when applied to Fischer. This is because Fischer teaches a commercial system that desires to have all of his transmissions received (i.e., intercepted) because if they are not, customers will not receive their TV broadcasts. Also, Fischer's system does not have radio frequency interference problems, as he communicates in designated frequency bands (see col. 3, lines 59-63). Radio frequency interference is a problem with ultra-wideband technology (i.e., Izadpanah), which is not taught or suggested in Fischer.

Therefore, the only motivation to combine is that provided by the Examiner's improper hindsight reconstruction. But the M.P.E.P. and case law requires that the motivation to combine references must be supplied by the references themselves. "[T]he best defense against the subtle but powerful attraction of hindsight-based obviousness analysis is rigorous application of the requirement for a showing of the teaching or motivation to combine prior art references", *In re Dembiczak*. 175 F.3D 994, 50 U.S.P.Q.2d 1614 (Fed. Cir. 1999). However, in this case the Examiner proposes to combine completely different technologies that operate in a fundamentally different manner. Therefore, the required motivation can only come from improper hindsight reconstruction.

2.   The proposed modification changes the principal of operation of the primary reference.

M.P.E.P. Section 2143.01(VI) states that "[i]f the proposed modification or

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combination of the prior art would change the principal of operation of the prior art invention being modified, then the teachings of the references are not sufficient to render the claims *prima facie* obvious."

Fischer teaches "conventional analog video transmission" that employs a continuous sine wave carrier signal that fits within a 6 Mega Hertz wide frequency band (col. 3, lines 61-63). Each 6 MHz wide channel is divided into 144 sub-channels of 33.3 Kilo Hertz each (col. 5, line 44-45).

In contrast, Izadpanah teaches an ultra-wideband beam former that transmits pulses which "can easily be of sub-nanosecond duration, for example, 100 picoseconds or less" (col. 5, lines 63-65). These "ultra-wideband" (UWB) pulses comprise a 5 GHz wide signal centered at the 20 Giga Hertz radio frequency (col. 7, lines 35-38).

Izadpanah's discrete pulses occupy 5 Giga Hertz of radio frequency spectrum. Fischer's continuous sine waves each occupy 33.3 Kilo Hertz of radio frequency spectrum. Each of Izadpanah's pulses is 151,000 times wider than Fischer's sine wave.

Fisher's antennas, looking for a 33.3 Kilo Hertz wide signal, would not even "see" a pico-second pulse that is 151,000 times wider, which is exactly the purpose of Izadpanah, which teaches "low probability of interception."

Fischer's principal of operation is the transmission and reception of conventional sine wave signals. Izadpanah's principal of operation is the transmission of pico-second pulses.

These technologies are apples and oranges, and neither reference teaches or suggests a communication system that employs both technologies.

Without using hindsight reconstruction, these two references would never be combined as suggested by the Examiner.

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Conclusion

For all of the reasons set forth above, Applicant respectfully submits that the rejection of claims 1-25 should be reversed. A Notice of Allowance is earnestly solicited.

Respectfully submitted,

Peter Martinez
Attorney for Applicant, Pulse-Link, Inc.
Reg. No. 42,845

APPENDIX A - APPEALED CLAIMS

1.   (Original) A communication system comprising:

a receiver structured to receive a substantially continuous sine wave carrier signal, the signal modulated to contain communication data;

a demodulator communicating with the receiver, the demodulator structured to demodulate the communication data from the substantially continuous sine wave carrier signal; and

a transmitter coupled to the demodulator, the transmitter structured to transmit a plurality of electromagnetic pulses, with the pulses configured to include the communication data.

2.   (Original) The communication system of claim 1, wherein the substantially continuous sine wave carrier signal is selected from a group consisting of: an amplitude modulated signal, a phase angle modulated signal, a frequency angle modulated signal, an orthogonal frequency division multiplexing modulated signal, a quadrature amplitude modulation signal, a dual sideband modulated signal, a single sideband modulated signal, and a vestigial sideband modulated signal.

3.   (Original) The communication system of claim 1, wherein the substantially continuous sine wave carrier signal has a radio frequency bandwidth that may range between about 10 kilohertz to about 5 megahertz.

4.   (Original) The communication system of claim 1, wherein the demodulator is selected from a group consisting of: an amplitude demodulation circuit, a quadrature amplitude demodulation circuit, a frequency angle demodulation circuit, a phase angle

demodulation circuit, and an orthogonal frequency division demodulating circuit.

5.   (Original) The communication system of claim 4, wherein the amplitude demodulation circuit is selected from a group consisting of: a dual sideband demodulation circuit, a single sideband demodulation circuit, and a vestigial sideband demodulation circuit.

6.   (Original) The communication system of claim 2, wherein the dual sideband modulated signal has a suppressed carrier.

7.   (Original) The communication system of 4, wherein the amplitude demodulation circuit comprises a low pass filter.

8.   (Original) The communication system of claim 2, wherein the single sideband modulated signal has a suppressed carrier.

9.   (Original) The communication system of claim 1, further including a first transmission medium coupled to the receiver, wherein the receiver receives the substantially continuous sine wave carrier signal through the first transmission medium.

10.   (Original) The communication system of claim 9, wherein the first transmission medium is a wireless medium.

11.   (Original) The communication system of claim 9, wherein the first transmission medium is selected from a group consisting of: an optical fiber ribbon, a fiber optic cable, a single mode fiber optic cable, a multi-mode fiber optic cable, a twisted pair wire, an

unshielded twisted pair wire, a plenum wire, a PVC wire, a coaxial cable, and an electrically conductive material.

12.   (Original) The communication system of claim 1, further including a second transmission medium coupled to the transmitter, wherein the transmitter transmits the plurality of electromagnetic pulses through the second transmission medium.

13.   (Original) The communication system of claim 12, wherein the second transmission medium is a wireless medium.

14.   (Original) The communication system of claim 12, wherein the second transmission medium is selected from a group consisting of: an optical fiber ribbon, a fiber optic cable, a single mode fiber optic cable, a multi-mode fiber optic cable, a twisted pair wire, an unshielded twisted pair wire, a plenum wire, a PVC wire, a coaxial cable, and an electrically conductive material.

15.   (Original) The communication system of claim 1, wherein each of the plurality of electromagnetic pulses comprises an ultra-wideband pulse.

16.   (Original) The communication system of claim 15, wherein each of the plurality of ultra-wideband pulses has a duration that ranges from about 10 picoseconds to about 10 milliseconds.

17.   (Original) The communication system of claim 1, wherein the transmitter comprises an ultra-wideband pulse modulator that is structured to transmit a multiplicity of ultra-wideband pulses.

18.   (Original) The communication system of claim 17, wherein the ultra-wideband pulse modulator is selected from a group consisting of: a pulse amplitude modulator, a pulse position modulator, a pulse duration modulator, a ternary pulse modulator, an on-off keying pulse modulator, a coded recurrence modulator, a sloped amplitude modulator, and a pulse phase modulator.

19.   (Original) The communication system of claim 1, wherein each of the plurality of transmitted electromagnetic pulses occupies substantially the same radio frequency spectrum.

20.   (Original) The communication system of claim 1, wherein each of the plurality of electromagnetic pulses is transmitted so that each pulse occupies a discrete portion of the radio frequency spectrum.

21.   (Original) The communication system of claim 1, wherein the communication data is selected from a group consisting of: voice data, video data, audio data, and high-definition video data.

22.   (Original) The communication system of claim 1, wherein the communication data is segmented into individual components selected from a group consisting of: received data, routing information, destination information, quality-of-service information, bit-error-rate information, priority information and latency information.

23.   (Original) The communication system of claim 1, wherein the communication data is received in a first communication format, segmented, and re-assembled in a second

communication format.

24.   (Original) The communication system of claim 23, wherein the second communication format comprises an ultra-wideband communication format.

25.   (Original) The communication system of claim 23, wherein the first communication format includes a format selected from a group consisting of: a substantially continuous sine wave carrier signal format; an amplitude modulated signal format, a phase angle modulated signal format, a frequency angle modulated signal format, an orthogonal frequency division multiplexing modulated signal format, a quadrature amplitude modulation signal format, a dual sideband modulated signal format, a single sideband modulated signal format, and a vestigial sideband modulated signal format.

APPENDIX B - EVIDENCE

Bruno Pattan, *A Brief Exposure to Ultra-Wideband Signaling*, Microwave Journal, (December 2003).

David G. Leeper, *Wireless Data Blaster*, Scientific American, 64, 69 (May 2002).

A Brief Exposure to Ultra-wideband Signaling

Ultra-wideband (UWB) techniques are based on the generation of extremely short digital pulses in the sub-nanosecond range (1 to 1000 picoseconds). The technology is vastly different from classical radio transmission. The extremely short pulses are generated at baseband and are transmitted without the use of a carrier. Their spectrum covers an extremely wide frequency range (1 to 10 GHz). The amount of power transmitted is a few milliwatts, which, when coupled with the spectral spread, produces very low spectral power densities. The FCC specifies that, between 3.1 and 10.6 GHz, the emission limits should be less than –41.3 dBm/MHz, or 75 nW/MHz. The total power between these limits is a mere 0.5 mW. These spectral power densities reside well below a receiver noise level. This tutorial brings the reader's attention to some of the peculiarities of this mode of signal transmission.

Baseband pulses are video or carrier-less pulses of very short duration. Their spectral content is concentrated primarily from zero frequency through the microwave region of the spectrum. This tutorial attempts to describe some of the vagaries of these pulses and their use in ground penetration radars and communications.

...the FCC tentatively defines UWB devices as those devices where the fractional bandwidth is greater than 0.25 or at least 25 percent of its center frequency.

Figure 1 depicts a picosecond monocycle in time and the envelope of the spectra for two different pulse lengths. The time display of a single-shot monocycle of energy may also represent a few cycles at a center frequency carrier. It is noticed that the monocycle spectrum is not uniform, as one would expect for an impulse in time (see example D in *Appendix A*). Integrating the power flux density (PFD) in watts/Hz under the envelope gives the total average power. If this were a continuous monocycle pulse train the spectra under the envelope would be discrete lines and separated by the pulse repetition frequency (see example B in Appendix A). If one curtails the pulse train (by gating with a gate width of T, for instance — see example C in Appendix A) each formally discrete spectral line will become a sinc function whose width is dictated by the gate width T. These concepts are shown in *Figure 2*. None of the waveforms shown at this juncture have coding or infor-

BRUNO PATTAN
Federal Communications Commission
Washington, DC

mation modulation. The pulse widths in UWB range from a few picoseconds to several nanoseconds. It may be recognized that different UWB applications operate best at different center frequency ranges. That is, one frequency may be more favorable for radar ground penetration and another for communication applications.

The monocycle pulse width establishes both the center frequency and energy distribution of the signal. For

(a)

(b)

▲ *Fig. 1 Time and spectral displays of monocycles; (a) time display of a single-shot monocycle and (b) spectral distribution of monocycles of two different lengths.*

▲ *Fig. 2 Spectrum envelopes of Gaussian monocycles.*

TIME

▲ *Fig. 3 Polycycle and monocycle wavelets imbedded in a Gaussian envelope.*

example, for a 300 ps pulse, the pulse has a center frequency of

$$f = \frac{1}{300 \cdot 10^{-12}} = 3 \ \text{GHz} \qquad (1)$$

For the longer pulse of 600 ps, the center frequency or the apex of the spectrum is

$$f = \frac{1}{600 \cdot 10^{-12}} = 1 \ \text{GHz} \qquad (2)$$

The monocycle has also been referred to as a Gaussian UWB monocycle. This suggests that the pulse envelope is a Gaussian curve. Note that a varying number of cycles under the envelope will determine the location of the center frequency. This is analogous to a rectangular RF pulse with different frequency under the envelope. **Figure 3** shows two pulses that have different center frequencies.

BANDWIDTH

The usual definition of the percentage bandwidth (from WWII days) is given by

$$\xi = \frac{\Delta f}{f_c} \cdot 100 \ \left(\text{percent}\right) \qquad (3)$$

where

Δf = difference between the lowest and highest frequencies
f_c = frequency of operation

For example, at S-band (2 to 4 GHz), the percentage bandwidth is

$$\frac{4-2}{3} \cdot 100 = 66 \ \text{percent}$$

Another definition is given as the relative or fractional bandwidth

$$\eta = \frac{\Delta f}{f_c} \qquad 0 \le \eta \le 1 \qquad (4)$$

where

Δf = absolute bandwidth
f_c = carrier (or center) frequency

Another way to express the bandwidth as a fraction of the center frequency is

$$BW = \frac{2\left(f_{hi} - f_{lo}\right)}{f_{hi} + f_{lo}} \qquad (5)$$

The definitions above beg the question — what is the value of the high and low frequencies? DARPA's definition is when the power at the frequen-

cies' extremes is down by 20 dB.

The FCC proposes to use the –10 dB points instead. Going from –20 to –10 dB requires a certain decrease of the numerical bandwidth. This is a practical choice since it may be difficult to measure down to –20 dB in the noise. It further requires that the –10 dB bandwidth must be between 3.1 and 10.6 GHz. The FCC restricts UWB communications activity to the frequency band between 3.1 and 10.6 GHz. In addition, the FCC sets emission limits equivalent to a transmission level of 75 nW/MHz between the limits 3.1 to 10.6 GHz. This amounts to an integral power

$$P_{(w)} = \int_{f_{lo}}^{f_{hi}} w(f) \qquad (6)$$

where

$w(f)$ = power flux density
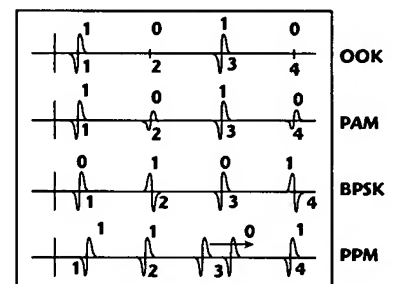$P_{(w)}$ = 75×10^{-9}(W/MHz) × (10.6–3.1) × 10^3 ≈ 0.5 mW

In the notice of proposed rule making (NPRM), the FCC tentatively defines UWB devices as those devices where the fractional bandwidth is greater than 0.25 or at least 25 percent of its center frequency. For example, for a center frequency of 2 GHz, it would occupy a bandwidth of 500 MHz or more, measured at the –10 dB signal strength. Clearly, this is instantaneous bandwidth.
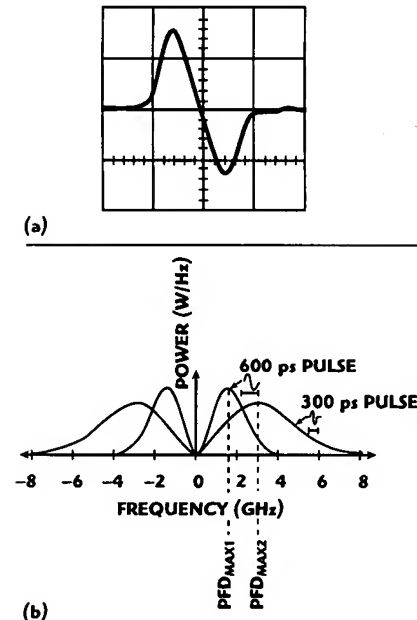
MODULATION

Four modulation schemes have been proposed for UWB systems. These are:

• On-Off Keying (OOK)
• Pulse Amplitude Modulation (PAM)
• Binary Phase Shift Keying (BPSK)
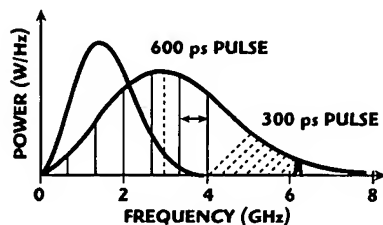• Pulse Position Modulation (PPM)
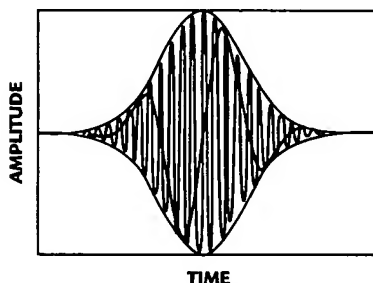
They are shown in **Figure 4**.

▲ *Fig. 4 Different modulations being considered for UWB signaling.*

Note in PPM, the maximum modulating signal must not cause a pulse to enter adjacent allotted slot intervals. In PPM, the pulses are dithered in time according to the baseband information. In addition to the modulation, spread spectrum may be introduced, not for the purpose of spreading the spectrum (UWB signal does that adequately), but for tagging the signals and matching them to their respective receivers (the code in the transmitter must be synchronized to the code in the receiver). This causes additional smearing of the spectrum and further lowers the power flux density. The PPM dithers the spectrum, but not to the extent that would occur if one uses pseudorandom coding. It has been suggested by some researchers that very high data rate PPM systems may result in timing problems in order to recover the signal. Others have proposed using bipolar modulation in order to alleviate this problem. In addition, it is claimed that bipolar modulation has a better power efficiency than PPM. Other modulations have been used for ground penetrating radars, including OOK. It appears that all these modulations have their niche.

Impulse communication employs front-end correlation in which the incoming RF signal is converted to baseband. This correlation is able to pick out the signal that resides below the receiver noise floor. This has been referred to as homodyne detection. This is really an inappropriate definition of homodyne, and is normally referred to as a zero IF mixer. Zero IF mixers are used to detect Dopplerized signals. Probably a better definition is an energy detector where all frequency information is lost, but pulse width and signal strength is retained. The increasing signal strength after integration is referred to as receiver gain.

MULTI-PATH IN UWB SYSTEMS

Generally, multi-path signals are not a problem in UWB systems. A multi-path resolution, down to a nanosecond in differential delay, is equivalent to a differential delay path of one foot. $d = c \cdot \Delta t = 3.10^8 \cdot 10^{-9} = 0.3$ m ≈ 1 ft. A multi-path that arrives at the receiver 2 ns later will not interfere with the pulse that arrived directly. The margin requirements are thus reduced. This is not unlike a situation in spread spectrum systems in which a bona-fide signal (direct) will be de-spread in the receiver, but its delayed version by one chirp will not correlate and is thus rejected but contributes to "hash" noise. Other codes not matched (orthogonal) will contribute additional hash. Tests performed by both UCLA and Lucent have verified the UWB phenomenon.

RANKING IN PERFORMANCE

It may be possible to enhance performance by "raking in" the multi-path signals that arrive at the receiver at different delays.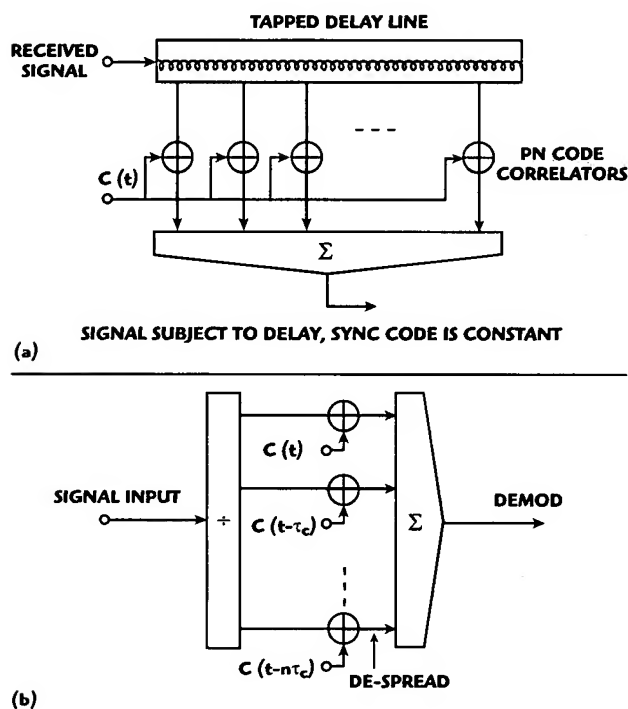 What immediately comes to mind are RAKE receivers. This concept has been used in low frequency propagation studies and more recently in cellular systems, in particular in systems using CDMA. RAKE receivers may now be put on a chip compared with the racks of equipment used by Price and Green in the 1958 time frame to manifest RAKE performance.

In a RAKE receiver, multiple replicas of the desired signal are received because of multi-path. Only the bona-fide or direct signal is in sync with the built-in receiver code, and thus is de-spread to receive the data message. In effect, the RAKE receiver "gathers up" various multi-path signals and increases the performance of the system. The multiple signals arriving at the receiver need to align themselves with the local code since they arrive at different times than the bona-fide signal. These multiple signals are generally delayed more than the spread signal chip width and thus can be recovered. The higher the chip rate, the more likely the echos with small delays can be processed by the RAKE receiver. For example, in the IS-95 CDMA cellular system, multi-path components that are less than 0.8 μs (chip width) apart cannot be separately identified or resolved.

Figure 5 shows two versions of a RAKE receiver. The first RAKE configuration is basically a delay line in which the signal is subjected to various delays. The tapped outputs are correlated with the local code, which is the same code that processes the bona-fide, non-faded signal.

The number of taps (fingers) on the delay line corresponds to the number of dominant multi-path signals that it is desirable to collect. There is a practical number of taps, above which there is a marginal improvement in performance. Five or six taps may be a reasonable number. The taps' location on the delay line may be adaptable since dominant echoes may vary in position if there is motion of the transmitter and/or the receiver. The location of dominants is performed by a "roving finger" or search finger and culls out the strongest multi-path for processing.

The total outputs of the taps are algebraically combined after the signals have been de-spread. That is, optimally combining via maximum ratio

▲ *Fig. 5 Two versions of RAKE receivers where the correct amount of delay can be inserted in either the received signals (a) or the local reference code (b).*

combining gives greater weight to the multi-path signals that have the highest signal-to-noise ratio. This artifice prevents the weaker signal from dragging down the composite signal-to-noise ratio.

In the second version of a RAKE receiver, the input signal drives a bank of correlators that are driven by the local code, subjected to different delays, as opposed to the delay line version where the code (undelayed) drives all correlators. The input multi-path signals will sync with one of these channels and are then summed.

CONCLUSION

In on-off keying a pulse is a one and the absence of a pulse is a zero. To the author's knowledge the military has been the main user of this form of modulation. Typically, the application is ground penetration radar.

In PAM, the amplitude is varied in two discrete steps for a zero and a one. However, in the presence of multi-path, it may be difficult to distinguish between a one or a zero because of the signal fluctuations due to multi-path.

In BPSK, the late half cycle (left side up) of the monocycle is used to represent a zero and the lead half (right side up) represents a one. There is no change in periodicity of the pulses. Researchers have indicated that by not dithering the pulses as in PPM permits sending pulses at a higher data rate. In addition, BPSK is more power efficient requiring less E_b/N_o than PPM to achieve the same BER.

In PPM, the difference between a one or a zero is determined by the arrival time of the pulses. That is, the pulses are dithered or changed in periodicity depending on whether a one or a zero has been sent. In the example, modulation for a long time lag, a zero was sent. For no time lag, a one was sent. Researchers have indicated for high data rates (proximity of the pulses) it may be difficult to accurately acquire the pulses. In the previously described signals, time jittering of the pulses may be used to avoid spectral spikes that may result from any periodicity.

It is this author's educated guess that eventually BPSK modulation will prevail because of its ease of implementation, power requirements and flexibility. BPSK, a binary system, gives the best BER for the minimum E_b/N_o (with no forward error correction). ∎

Bruno Pattan *is an electronics engineer at the FCC's Office of Engineering and Technology. He worked for many years as a radar system engineer at Sylvania (GTE), Lockheed and United Technologies, and on MILS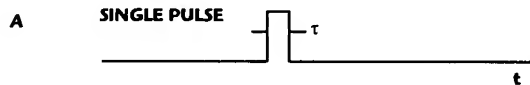ATCOMS studies at Computer Sciences. He has published several papers and is the author of three books. He is a senior member of both the IEEE and the AIAA.*
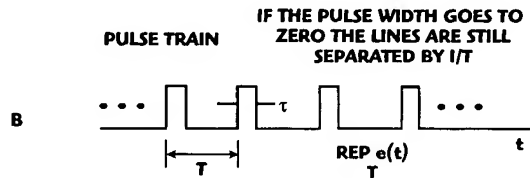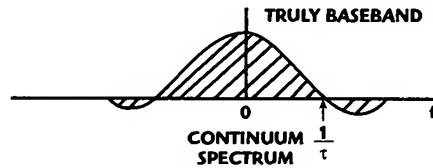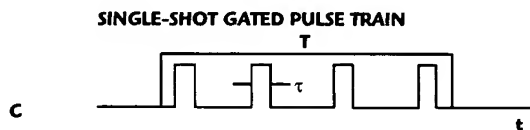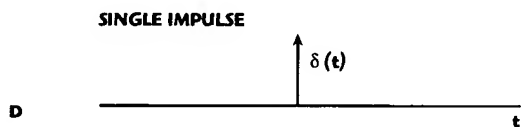
APPENDIX A

TIME WAVEFORMS

THEIR SPECTRA

A

SINGLE PULSE τ

$< = >$

TRULY BASEBAND

0   f

CONTINUUM SPECTRUM $\frac{1}{\tau}$

B

PULSE TRAIN

IF THE PULSE WIDTH GOES TO ZERO THE LINES ARE STILL SEPARATED BY 1/T

τ

T

REP $e(t)$ T

$< = >$

SEPARATED BY PRF

f

$\frac{2\pi}{T}$ COMB $_{\frac{2\pi}{T}}$ $E(W)$ DISCRETE SPECTRAL LINES

C

SINGLE-SHOT GATED PULSE TRAIN

T

τ

$< = >$

SINC WIDTHS FUNCTION OF GATE WIDTH

$\frac{1}{T}$ CONTINUUM SPECTRA UNDER SINCS $\frac{1}{\tau}$

D

SINGLE IMPULSE

$\delta(t)$

$< = >$

$\delta(\omega) = \int_{-\infty}^{\infty} \delta(t) \exp(-j\omega t)\, dt = 1$

- - - - - - - 1

CONTINUUM

E

IMPULSE TRAIN

PPM*   SPECTRUM DITHER

1

0

PROGRAMMED IMPULSE DELAYS SMEAR THE SPECTRUM

$< = >$

SPECTRAL LINES AT MULTIPLES OF PULSE RATE

f

DELTA SPIKES IN FREQUENCY

F

SINGLE-SHOT GATED IMPULSE TRAIN
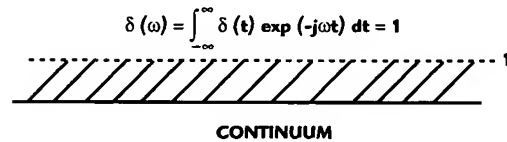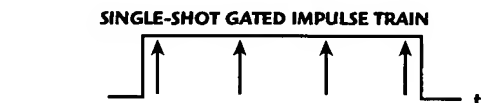
$< = >$

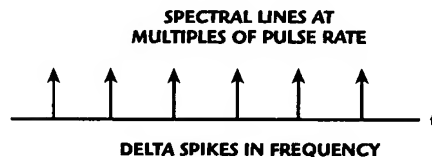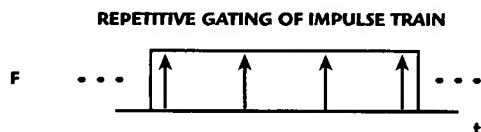PAM MODULATION OF TIME DELAYS (REDUCES POWER FLUX DENSITY (W/Hz))
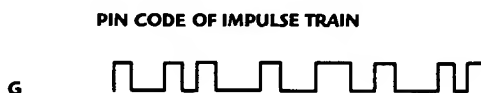
f

CONTINUA SPECTRA

REPETITIVE GATING OF IMPULSE TRAIN

$< = >$

f

DISCRETE SPECTRAL LINES
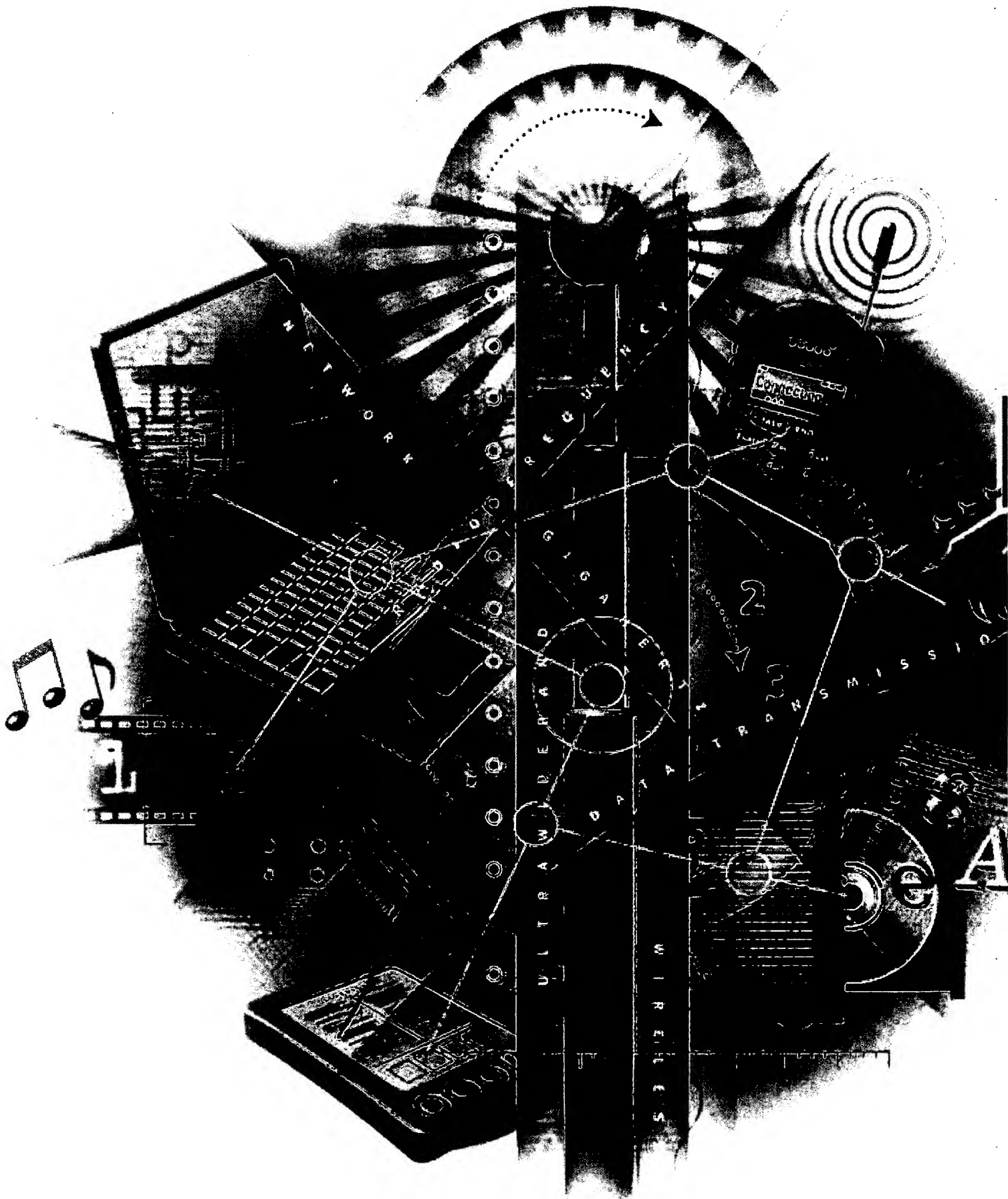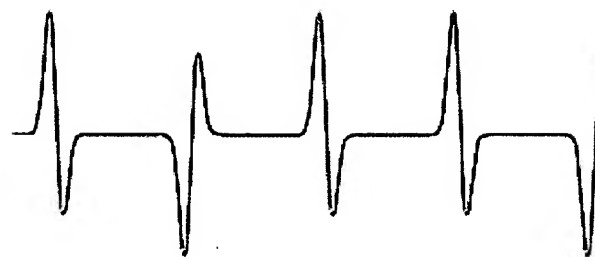
G

PIN CODE OF IMPULSE TRAIN

$< = >$

f

QUASI-CONTINUOUS SPECTRUM

*PN CODING FURTHER SMEARS THE SPECTRUM ABOVE THAT WHICH IS CAUSED BY PPM ALONE (MAY BE FURTHER USED FOR TAGGING DIFFERENT UWB SIGNALS)

Wireless
Data Blaster

Radio's oldest technology
is providing a new way
for portable electronics
to transmit large quantities
of data rapidly without wires

By David G. Leeper

With a crackling sound like that of frying eggs, an undulating thread of intense, blue-white light dances across the small space between the tips of two metal rods. Using his spark-gap transmitter, a mild-mannered 31-year-old physics professor demonstrates electromagnetic phenomena to students in a dimly lit classroom at the University of Karlsruhe in Germany. The year is 1887, and Heinrich Hertz is generating radio waves. Seven years later a young Italian named Guglielmo Marconi reads a journal article by Hertz while vacationing in the Alps and abruptly rushes home with a vision of a wireless telegraph in his head. Soon Marconi's own spark-gap transmitters are sending Morse-code pulse streams across his lab without wires. After boosting power and building much larger antennas, the radio pioneer eventually uses the device to transmit coded wireless signals across the Atlantic Ocean in 1901.

Fast-forward a century, and researchers are once again beaming short electromagnetic pulses across their labs. But the technology has changed. Hertz's and Marconi's bulky coils and capacitors have been replaced by tiny integrated circuits and tunnel diodes. Likewise, the ragged and erratic spark streams emitted by early transmitters have now been refined into precisely timed sequences of specially shaped pulses lasting only a few hundred trillionths of a second each. And whereas Marconi's devices could convey the equivalent of about 10 bits of data per second, today's short-range, low-power descendant of the original spark-gap systems—called ultrawideband (UWB) wireless technology—can send more than 100 million bits of digital information in the same amount of time.

Just Get Me to the Wall

THE HIGH-SPEED data-transfer capabilities of UWB systems have spurred a group of inventors and entrepreneurs [see table below] to promote this short-range technology as a nearly ideal way to handle the burgeoning flow of wireless information among networks of portable (battery-powered) electronic devices. These stand-alone networks could include personal digi-

tooth standards, which operate in an unlicensed frequency band from 2.400 to 2.483 gigahertz (GHz), and IEEE 802.11a, which operates indoors on frequencies from 5.150 to 5.350 GHz.

Bluetooth is the best known of what are commonly called wireless personal-area networks (PANs). Wireless PANs were designed to replace the (physical) serial and USB cables used to pass data among closely located electronic equipment. Although specific implementations differ, the low-power Bluetooth standard is expected to offer users a maximum data-transmission speed of about 700 kilobits per second over distances of up to about 10 meters.

The IEEE 802.11a and 802.11b standards were established for wireless local-area networks (LANs), which emphasize faster speeds and longer range but require higher-power consumption. Typically these wireless LANs provide links from laptops to wired LANs via access points. Users of IEEE 802.11b can expect maximum transmission speeds of about 5.5 megabits per second (Mbps) across open-space distances of up to 100 meters. Its companion standard, IEEE 802.11a, will provide users with maximum data speeds of between 24 to 35 Mbps over open spaces of about 50 meters. In practice, all

Ultrawideband wireless technology should make possible an entirely NEW CLASS OF ELECTRONIC DEVICES and functions that would change the way we live.

tal assistants, digital cameras and camcorders, audio/video players, cell phones, laptop computers and other mobile electronic gear. To exchange the large digital files needed to support increasingly sophisticated broadband applications, these devices require high-bandwidth wireless communications links.

The growing presence of wired connections to the Internet is another driver of short-distance wireless technology. Many in the developed world already spend most of the day within 10 meters of some kind of wired link to the Internet. This proximity opens up the possibility of using short-range wireless technology to communicate between portable electronics and the Internet. As a result, the industry has responded by developing narrowband communications techniques that can "get me to the jack on the wall." These include the IEEE 802.11b and Blue-

short-range radio systems "downshift" their speeds to compensate for long distances, walls, people and other obstacles.

At present, it appears that semiconductor-based UWB transceivers will be able to provide very high data transmission speeds—100 to 500 Mbps across distances of five to 10 meters. These high bit rates will give rise to applications that are impossible using today's wireless standards. What is more, engineers expect these UWB units to be cheaper, smaller and less power-hungry than today's narrowband radio devices.

UWB is superior to other short-range wireless schemes in another way. Growing demand for greater wireless data capacity and the crowding of regulated radio-frequency spectra favor systems that offer not only high bit rates but high bit rates concentrated in smaller physical areas, a metric that has come to be called spatial capacity. Measured in bits per second per square meter, it is a gauge of "data intensity" in much the same way that lumens per square meter determines the illumination intensity of a light fixture. As increasing numbers of broadband users gather in crowded spaces such as airports, hotels, convention centers and workplaces, the most critical parameter of a wireless system will be its spatial capacity, a capability in which UWB technology excels [see graph on opposite page].

Successful development of UWB wireless technology should make possible an entirely new class of electronic devices and functions that would change the way we live. For example, rather than picking up recorded movies at the video store, we

UWB DEVELOPERS	
Aether Wire & Location	www.aetherwire.com
General Atomics	www.ga.com
Multispectral Solutions	www.multispectral.com
Pulse-Link	www.pulse-link.net
Pulsicom Technologies (Israel)	www.pulsicom.com
Time Domain	www.timedomain.com
XtremeSpectrum	www.xtremespectrum.com
Zircon	www.zircon.com

may end up downloading films using a portable mass-storage unit and UWB wireless transmission while filling the car up at the fuel pump. UWB could permit bulky PDA calendars and e-mail directories to be flash-synchronized or messages to be sent or received in public places such as coffee shops, airports, hotels and convention centers. While traveling on planes or trains, people could enjoy streaming video input or interactive games on three-dimensional-vision eyeglasses and high-fidelity audio sets equipped with UWB. Photoenthusiasts could download digital images and video from their cameras to computers or home theaters via UWB wireless, eliminating the rat's nests of cables we often use today.

Comparison of Short-Range Wireless Spatial Capacities

SPATIAL CAPACITY, a gauge of operational efficiency important when comparing short-range wireless systems, favors UWB technology. Measured in kilobits per second per square meter (kbps/m²), spatial capacity focuses not only on bit rates for data transfer but on bit rates available in the confined spaces defined by short transmission ranges.

UWB technology has other significant, noncommunications applications as well. It relies on razor-thin, precisely timed pulses similar to those used in radar applications. These pulses give UWB wireless the ability to discern buried objects or movement behind walls, capabilities that could be important for rescue and law-enforcement missions.

UWB's precision pulses can also be used to determine the position of emitters indoors. Operating like a local version of the Global Positioning System (GPS) or the LoJack anti-auto-theft technology, a UWB wireless system can triangulate the location of goods tagged with transmitters using multiple receivers placed in the vicinity. This ability might be very useful to department store personnel for doing "virtual inventories"—keeping track of high-value products on the shelves or in the warehouse, for instance. This location-finding feature could also be used to enhance security: UWB receivers installed in "smart" door locks or ATM machines could permit them to operate only when an authorized user—carrying a UWB transmitter—approaches to within a meter or less.

Radio with No Carrier

ULTRAWIDEBAND WIRELESS is unlike familiar forms of radio communications such as AM/FM, short-wave, police/fire,

radio, television, and so forth. These narrowband services, which avoid interfering with one another by staying within the confines of their allocated frequency bands, use what is called a carrier wave. Data messages are impressed on the underlying carrier signal by modulating its amplitude, frequency or phase in some way and then are extracted upon reception [see box on next page for modulation techniques].

UWB technology is radically different. Rather than employing a carrier signal, UWB emissions are composed of a series of intermittent pulses. By varying the pulses' amplitude, polarity, timing or other characteristic, information is coded into the data stream. Various other terms have been used for the UWB transmission mode—carrierless, baseband, nonsinusoidal and impulse-based among them.

Avoiding Interference

BECAUSE OF THEIR EXTREMELY short duration, these ultrawideband pulses function in a continuous band of frequencies that can span several gigahertz. It turns out that the shorter the pulse, the broader the frequency spectrum that the pulse will occupy [see box on next page for an explanation of this phenomenon].

Because the UWB pulses employ the same frequencies as traditional radio services, they can potentially interfere with them. Marconi's spark-gap stations used high power because they needed to bridge great distances. In today's regulatory environment, systems like Marconi's would be intolerable because they would interfere with almost everybody else on the air. Ultrawideband communications systems would share the same problem except that they deliberately operate at power levels so low that they emit less average radio energy than hair dryers, electric drills, laptop computers and other common appliances that radiate electromagnetic energy as a by-product. This low-power output means that UWB's range is sharply restricted—to distances of 100 meters or less and usually as little as 10 meters. For well-chosen modulation schemes, interference from UWB transmitters is generally benign because the energy levels of the pulses are simply too low to cause problems.

As with emissions from home appliances, the average radiated power from UWB transceivers is likewise expected to be too low to pose any biological hazard to users, although further laboratory tests are needed to confirm this fully. A typical 200-microwatt UWB transmitter, for example, radiates only one three-thousandth of the average energy emitted by a conventional 600-milliwatt cell phone.

On February 14 the Federal Communications Commission

THE AUTHOR

DAVID G. LEEPER is chief technologist for wireless technologies in Intel's New Business Investments Group, which is exploring commercial applications for ultrawideband wireless systems. During his 32-year career, he has also held senior management positions at AT&T Bell Labs, Bellcore and Motorola. Leeper enjoys working with small teams to create business opportunities around exciting new technologies. He received a doctorate in electrical engineering from the University of Pennsylvania.
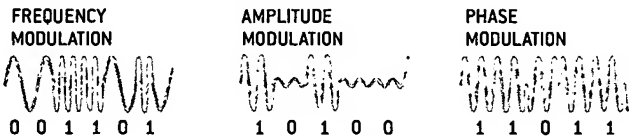
Narrowband and Wideband Modulation Schemes

CONVENTIONAL NARROWBAND radio techniques rely on a base "carrier" wave that is altered in a systematic manner (modulated) to embody a coded bit stream. Carrier waves can be modified to incorporate digital data by varying their amplitude, frequency or phase.
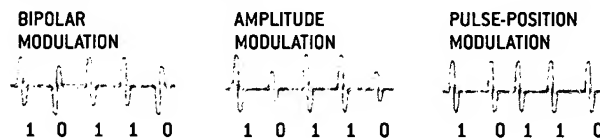
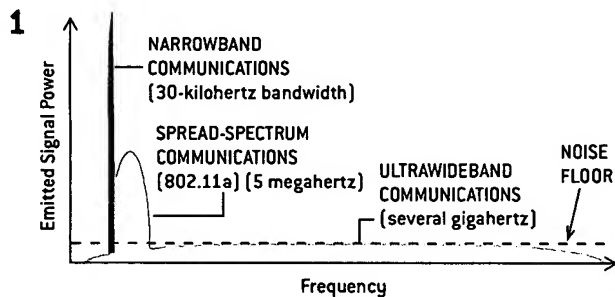Ultrawideband wireless technology uses no underlying carrier wave, instead modulating individual pulses in some way. In a bipolar modulation scheme, a digital 1 is represented by a positive (rising) pulse and a 0 by an inverted (falling) pulse. In another approach, full-amplitude pulses stand for 1's, whereas half-amplitude pulses stand for 0's. Pulse-position modulation sends identical pulses but alters the transmission timing. Delayed pulses indicate 0's.

Narrowband Transmissions

FREQUENCY MODULATION

0 0 1 1 0 1

AMPLITUDE MODULATION

1 0 1 0 0

PHASE MODULATION

1 1 0 1 1

Wideband Transmissions

BIPOLAR MODULATION

1 0 1 1 0

AMPLITUDE MODULATION

1 0 1 1 0

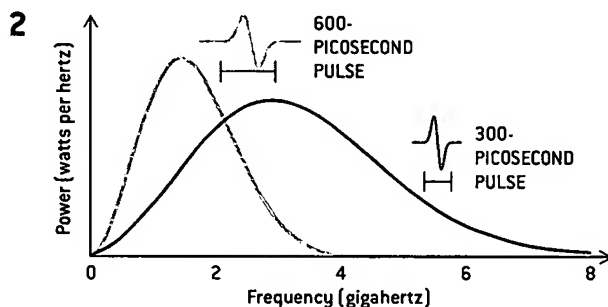**PULSE-POSITION MODULATION**

1 0 1 1 0

Why Short Pulses Imply Wide Frequency Bands

UNLIKE TRADITIONAL COMMUNICATIONS systems, ultrawideband wireless occupies a broad span of frequencies at very low power levels, often below the noise floor of the existing signaling environment (1).

is weaker than the previous one, but the approximation improves with each addition. In principle, an infinite number of additions exactly represents the square wave, but as shown below (3), the fundamental plus its first four odd harmonics do a fairly good job.

1

Emitted Signal Power

NARROWBAND COMMUNICATIONS (30-kilohertz bandwidth)

SPREAD-SPECTRUM COMMUNICATIONS (802.11a) (5 megahertz)

ULTRAWIDEBAND COMMUNICATIONS (several gigahertz)

NOISE FLOOR

Frequency

3 Fourier Approximation of a Square Wave Pulse

FUNDAMENTAL

FUNDAMENTAL + 1/3 THIRD HARMONIC

FUNDAMENTAL + 1/3 THIRD + 1/5 FIFTH HARMONICS

FUNDAMENTAL + 1/3 THIRD + 1/5 FIFTH + 1/7 SEVENTH HARMONICS

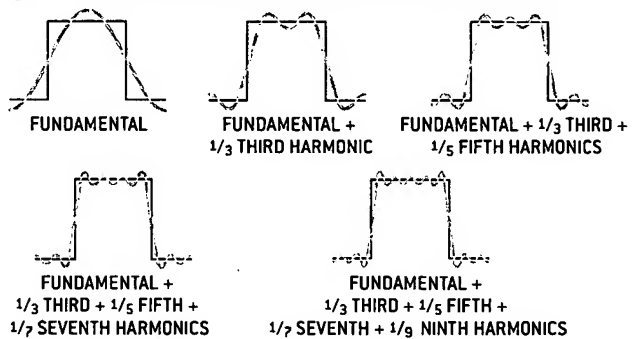FUNDAMENTAL + 1/3 THIRD + 1/5 FIFTH + 1/7 SEVENTH + 1/9 NINTH HARMONICS

The comparison below (2), which depicts typical ultrawideband pulses and their accompanying frequency spectra, shows that the narrower the pulse in time, the higher its center frequency and the broader the spread of its frequency spectrum. (Picoseconds are trillionths of seconds.)

2

Power (watts per hertz)

600-PICOSECOND PULSE

300-PICOSECOND PULSE

0   2   4   6   8
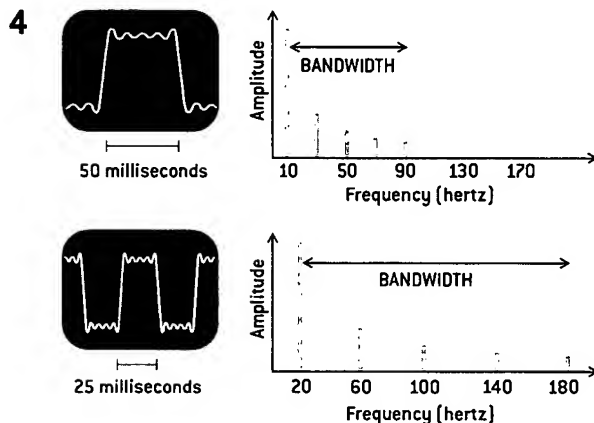
Frequency (gigahertz)

Fourier transform theory explains why the shorter the time interval of a pulse, the broader its bandwidth. The theory says that any waveform can be represented as the appropriately weighted sum of sinusoidal waveforms. For example, a square pulse (in reality, a train of them) can be approximated by a sine wave fundamental (or root) plus sine waves whose frequencies are odd multiples (harmonics) of the fundamental's frequency. Each added harmonic

The figures below (4) show the distribution of energy in the fundamental and harmonic waves as functions of their frequencies for Fourier approximations of two pulses. Note that the narrower pulse requires a higher fundamental frequency to represent it. The four added harmonics of that fundamental have a larger spread (or bandwidth) than that of the wider pulse.

4

50 milliseconds

Amplitude

BANDWIDTH

10   50   90   130   170

Frequency (hertz)

25 milliseconds

Amplitude

BANDWIDTH

20   60   100   140   180

Frequency (hertz)

gave qualified approval to UWB usage, following nearly two years of commentary by interested parties. Most of the more than 900 comments on the proposed ruling concerned whether UWB might interfere with existing services such as GPS, radar and defense communications, and cell-phone services.

Taking a conservative tack, federal regulators chose to allow UWB communications applications with full "incidental radiation" power limits of between 3.1 and 10.6 GHz. Outside that band, signals must be attenuated by 12 decibels (dB), with 34 dB of attenuation required in areas near the GPS-frequency bands. More liberal restrictions were permitted for law-enforcement and public safety personnel using UWB units to search for earthquake or terrorist attack victims.

Despite the imposed limitations, UWB developers are confident that the wireless technology will be able to accomplish most of the data-transfer tasks its proponents envision for it. The FCC regulators indicated that they will examine easing the constraints once operational experience has been gained and further studies have been conducted.

noisy and distorted. Rolling forward a foot or two, however, often alters the relative timing of the received signals sufficiently to restore clear reception.

Multiple signals caused by reflections might be a liability for UWB wireless units as well, but clever design can permit them to take advantage of the phenomenon. The narrow pulses of UWB make it possible for some receivers to resolve the separate multipath streams and use multiple "arms" to lock onto the various reflected signals. Then, in near real-time, the arms "vote" on whether a received bit is a one or a zero. This bit-checking function actually improves the performance of the receiver.

Go Low and Short

TODAY'S TREND TOWARD sending lower-power signals over shorter ranges has occurred previously in wireless communications—during the early days of radio telephony. Before 1980, a single tower with a high-powered transmitter might cover an entire city, but limited spectrum availability meant that it could not serve many customers. As recently as 1976, radio

A typical 200-microwatt UWB transmitter radiates only ONE THREE-THOUSANDTH OF THE AVERAGE ENERGY emitted by a conventional 600-milliwatt cell phone.

Ironically, the more challenging technical problem appears to be finding ways to stop other emitters from interfering with UWB devices. This area is one in which narrowband systems have a decided advantage—all such systems are fitted with a front-end filter that prevents transmitters operating outside their reception bands from causing trouble. Unfortunately, a UWB receiver needs to have a "wide-open" front-end filter that lets through a broad spectrum of frequencies, including signals from potential interferers. The ability of a UWB receiver to overcome this impediment, sometimes called jamming resistance, is a key attribute of good receiver design. One approach to improving jamming resistance is to install so-called notch filters that attenuate those narrow parts of the spectrum where interference is known to be likely. Another protective measure that has been developed would be to use automatic notch filters that seek out and diminish the signals of particularly strong narrowband interferers.

Many Paths to Take

MULTIPATH INTERFERENCE, another kind of radio interference, is also an issue. In some situations, the same narrowband signal can be reflected by surrounding objects onto two or more different paths so the reflected signals arrive at a receiver out of phase, sometimes virtually canceling each other out. Most of us have experienced multipath problems when listening to FM radio in an automobile. When a car is stopped at a traffic light, for example, the signal can suddenly become

telephone providers in New York City could handle only 545 mobile telephone customers at a time—an absurdly small number by current standards. Cellular telephony was able to accommodate a greater number of customers by drastically reducing both power and distance, allowing the same spectrum to be reused many times within a geographic area. Now short-range wireless, particularly UWB, is poised to do the same.

There are still some among us who can remember, before 1920, when "spark was king." With help from semiconductors and the Internet, spark-gap radio's latter-day offspring—UWB technology—may soon emerge as a major wireless building block for advanced high-speed data communications. $\boxed{\text{SA}}$

MORE TO EXPLORE

Ultra-Wideband Technology for Short or Medium-Range Wireless Communications. J. Foerster et al. in *Intel Technology Journal*, 02, 2001. Available at http://intel.com/technology/itj/q22001/articles/art_4.htm

A Long-Term View of Short-Range Wireless. David G. Leeper in *IEEE Computer Magazine*, Vol. 34, No. 6, pages 39–44; June 2001.

Extensive links to UWB wireless information sources: www.aetherwire.com

FCC electronic comment-filing system: www.fcc.gov/e-file/ecfs.html (Click on "Search for Filed Comments" and enter "98-153" in the box.)

History of radio Web site: www.localhistory.scit.wlv.ac.uk/Museum/Engineering/Electronics/history/radiohistory.htm

Official Bluetooth Web site: www.bluetooth.com

Official IEEE 802 Web site: http://grouper.ieee.org/groups/802

APPENDIX C - RELATED PROCEEDINGS

None (this sheet made necessary by 69 Fed. Reg. 155 (August 2004), page 49978.)